Petrified Forests of Yellowstone

Handbook 108

Petrified Forests of Yellowstone

Yellowstone National Park
Wyoming, Montana, and Idaho

Produced by the
Division of Publications
National Park Service

U.S. Department of the Interior
Washington, D.C. 1980

The National Park Handbook Series
National Park Handbooks, compact introductions to the great natural and historic places administered by the National Park Service, are designed to promote understanding and enjoyment of the parks. Each is intended to be informative reading and a useful guide before, during, and after a park visit. More than 100 titles are in print. They are available by mail from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

About This Book
Among Yellowstone's many scenic and scientific features, few are more wondrous than its little-known petrified forests. But knowledge regarding the fossil forests remains limited and changing. In this book, Dr. Erling Dorf of Princeton University tells the story of Yellowstone's petrified forests, and how these giant mineralized stumps most likely came into being. An earlier version of this story appeared in the April 1964 issue of ''Scientific American.''

Library of Congress Cataloging in Publication Data
Dorf, Erling, 1905-
Petrified forests of Yellowstone.
(Handbook—National Park Service; 108)
Supt. of Docs. no.: I 29.9/5:108
1. Petrified forests. 2. Paleobotany—
Eocene. 3. Paleobotany—Yellowstone National
Park. 4. Yellowstone National Park. I. United States.
National Park Service. II. Title. III. Series: United
States.
National Park Service.
Handbook—National Park Service; 108.
QE991.D67 561'.21'0978752 80-607157

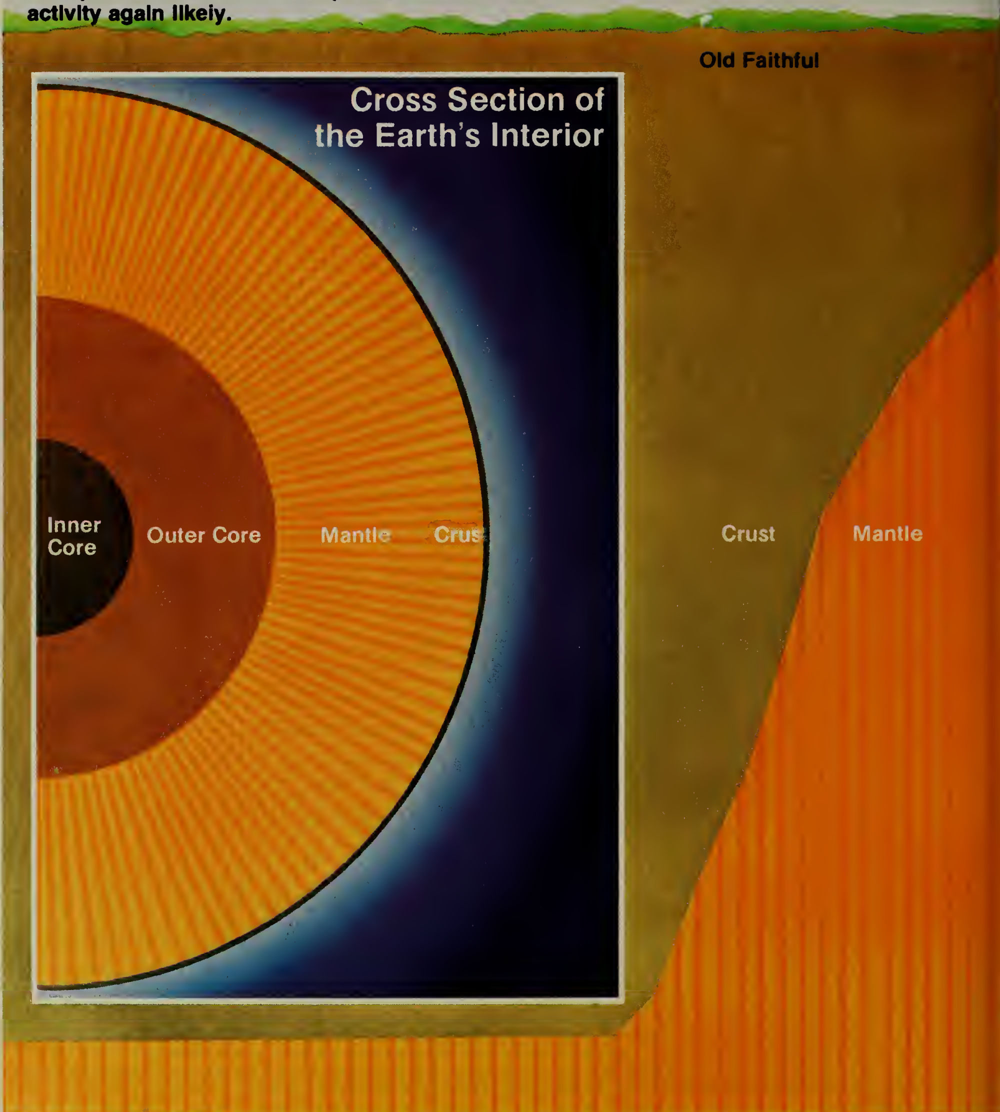
Contents

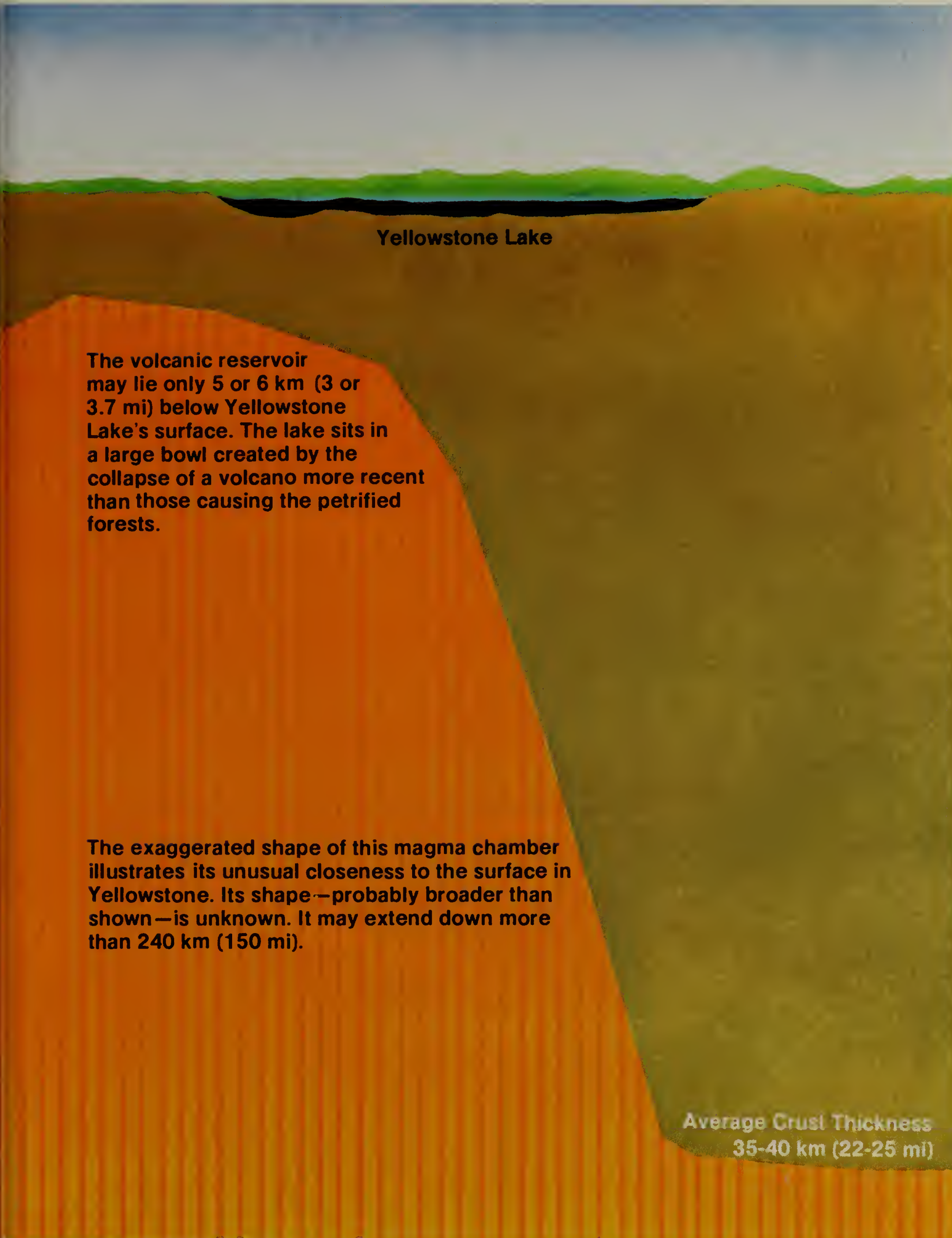
Petrified Forests of Yellowstone

By Erling Dorf, Princeton University

Yellowstone's Hot Spot

Hot magma inside the earth appears to be remarkably close to the surface in Yellowstone. This explains the park's unique geology and its heat-related features. In Eocene times volcanic eruptions repeatedly buried entire forests and these became petrified. Scientists think this hot spot makes further earthquakes certain and volcanic activity again likely.




Yellowstone Lake
The volcanic reservoir may lie only 5 or 6 km (3 or 3.7 mi) below Yellowstone Lake's surface. The lake sits in a large bowl created by the collapse of a volcano more recent than those causing the petrified forests.
The exaggerated shape of this magma chamber illustrates its unusual closeness to the surface in Yellowstone. Its shape—probably broader than shown—is unknown. It may extend down more than 240 km (150 mi).
Average Crust Thickness
35-40 km (22-25 mi)

A Story Told by Heat, Water and Time

Magic. You look at Yellowstone National Park's fantastic features and see magic. No matter how much you understand the what, where, when, how, and why of this wonderland, its magical qualities remain. Our minds may grasp the immense age and processes geologists detect in the earth's crust, but our feelings remain paramount. Confronted with geysers, mud pots, fumaroles, and majestic waterfalls, a part of us still tips its hat to magic.

Is it magician's work to turn wood into stone? If so, the magician must be time. Even the best sorcerers use apprentices, of course, and volcanoes and rain have lent a hand to time for this huge task.

The petrified forests of Yellowstone were slowly turned to stone millions of years before man uttered the words *to petrify*. We still don't completely understand the petrifaction process, this turning of things to stone. In time perhaps we will, but for now we do know this: Fiery volcanoes buried living forests in ash and mudflows, and mineral-bearing hot water slowly petrified them. Water again, through the process of erosion, exposed them to our view.

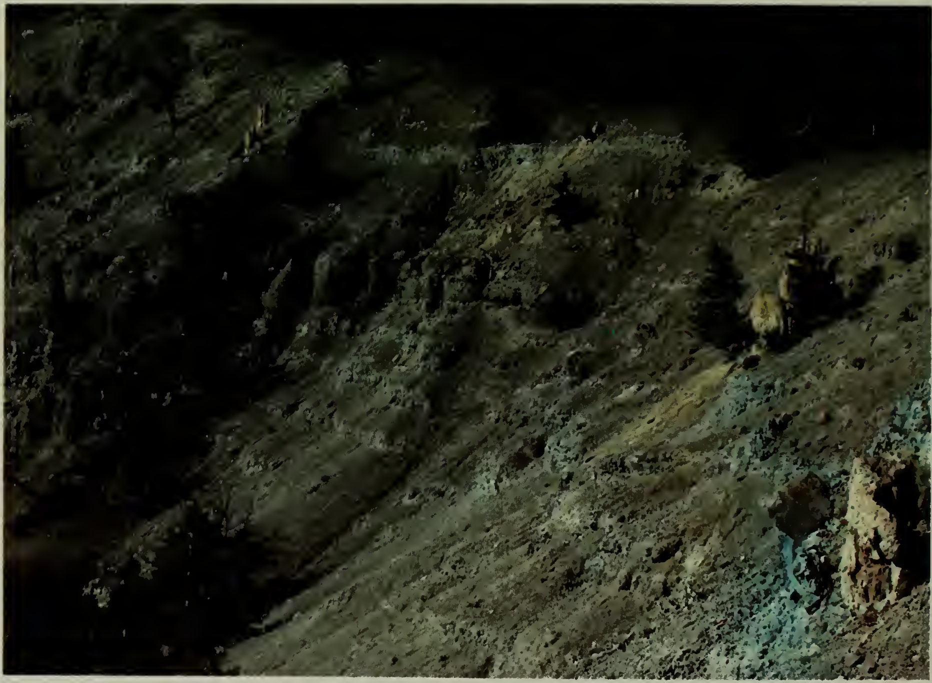
Heat, water, and time. To these belongs the story of Yellowstone's petrified forests, a story of the earth in upheaval over the long haul of geologic time.

Jim Bridger's Petrified Light

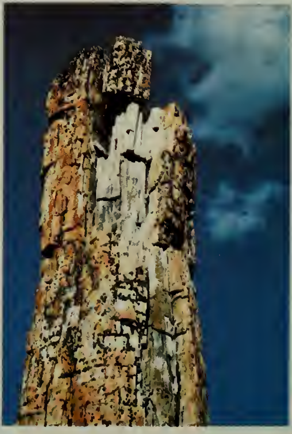
Jim Bridger was among the first whites to see these petrified forests. He was no magician, but he could stretch the truth so far that it turned into a tall tale. Mountain man, fur trapper and trader, scout and guide, he was a famous spinner of yarns. Naturally, he contrived an explanation for the petrified forests of Yellowstone.

A great Crow Indian medicine man once cursed a mountain, Bridger said, and instantly everything on it was petrified, doomed to stand frozen in time. Sagebrush, grass, prairie fowl, antelope, elk, and bears could be seen as perfect as in actual life. Flowers bloomed in colors of crystal, and birds soared with wings spread to motionless flight. Even the sun

Greatly magnified, this bit of an ancient Yellowstone tree typifies the silent records stored in Yellowstone's little-known fossil forests. Annual growth rings representing years in past eons contrast with today's pine needles fallen on the petrified wood's exposed surface.



Jim Bridger (top) told tall tales about Yellowstone's petrified forests such as those exposed on Specimen Ridge (above). The forests are remarkable for their extent and the fact that many tree stumps are preserved in an upright position (right).



and the moon shone here with petrified light, he maintained.

No doubt Bridger's explanation delighted his campfire companions, but it differs substantially from the story geologists tell. In fact, Bridger's many tall tales actually delayed the serious exploration of the Yellowstone region. No one believed it existed because all the stories about it sounded like, well, tall tales.

But stop a minute. Imagine *you* are Jim Bridger. Passing through trackless wilderness you come upon large, standing tree stumps that aren't wood, but stone. What would you tell the next person you met? Would you describe the stone trees as pillars of some great ruins like those in ancient Greece or Rome? What questions would you ask yourself in fishing for an explanation of their origin and significance? Would anyone believe you, no matter what you said?

The unusual demands to be shared. Some things are so unusual we want to call them unnatural or associate them with more familiar man-made phenomena. Jim Bridger's explanation placed the cause of the petrified forests outside nature, attributing it to the medicine man's supernatural curse.

Disciplined wondering about the earth's crust falls to geologists. Geology represents an organized attempt to satisfy our curiosity about these aspects of the earth. Sometimes the study starts from an observation and works backwards. You discover petrified forests, for example, and try to work out an explanation. Sometimes you proceed in the other direction. Equipped with an understanding of certain geologic features you search for oil, copper, coal, or gold in likely locations. Or maybe you need to dig a new water well. Knowledge of geology can reduce the risk of drilling a dry hole.

A geologist he was not, but credit Jim Bridger with this: he sensed that a mountain was partly responsible for petrifying these forests. If he had known the mountain blew its top, what a yarn he would have spun!

Author Erling Dorf, professor emeritus at Princeton University, began studying the fossil forests in 1954. He once served as a Yellowstone park naturalist.

Endless Clouds of Ash and Dust

The fossil forests occur in a rugged, wilderness setting. Naturalist-guided hikes tour the area during summer months.

What really did happen? We can't know for sure. Obviously, there are no eyewitness accounts of prehistoric events. Geologists have pieced together a story about what might have happened, however. Clues have come from the earth's crust; the trees themselves and how they stand; and the fossils and how they were preserved. The story goes like this:

Earthquakes had shaken the quiet, forested valley several times a day for more than ten days. On the eleventh day the violence of the quakes increased. Small bands of frightened animals sprinted through the underbrush futilely searching out a quiet spot. Tall, magnificent redwood trees and spreading sycamores shook, swayed, and bounded about as though struck by a hurricane. Overhead, like a noisy nightmare, the high-pitched shrieks of hundreds of frightened birds could be heard for kilometers.

Suddenly above the din a deafening explosion seemed to shake the whole world. Off to the south the slumbering old volcano had suddenly come to life and literally blown its top. Within minutes rocks began to rain down on the wooded slopes of the old mountain and its surrounding valleys for a distance of about 8 kilometers (5 miles). From the newly formed crater atop the mountain almost continuous explosions belched forth a dense, billowing cloud of hot volcanic ash, dust, and steam, mixed with coarser fragments of rocks and red-hot blobs of lava.

Within hours the sun was completely hidden. Gray darkness spread slowly in all directions. Even the green forested valley was showered by the rain of volcanic debris. The birds and mammals had already fled swiftly in all directions to escape the noxious fumes and dust. Most of the trees had lost some branches and many leaves, needles, and cones from the force of the winds and the weight of the heavy ash on their surfaces. These plant remains were soon buried as the debris and ash rapidly accumulated on the forest floor.

The majestic river and its tributaries soon choked on their loads of ash and volcanic fragments. Sluggish waters overflowed banks and began to deposit their soggy debris in long irregular channels throughout

the forest. The scene stood in stark contrast to the former lush splendor of the valley.

The eruptions from the old volcano seemed destined to go on for a long, long time. Hour after hour, day after day the endless clouds of ash and dust and heavier volcanic debris continued to be blown skyward from the rejuvenated crater. As the rain of debris slowly settled on the surrounding region, the landscape assumed a look of utter desolation. Within a year most of the tree trunks stood buried in the volcanic debris to depths of about 1.8 meters (6 feet). Not a leaf or needle remained on any of their smooth, bare branches now starkly silhouetted against the gray, dusty sky. Not a single bird or beast or even insect had been able to return to the region since the first volcanic outburst.

As the years passed, the old volcano gradually lost its punch and fury. Eruptions became less frequent—sometimes only three or four a day—so the atmosphere slowly cleared. Before the end of the twentieth year volcanic activity ceased altogether. The old volcano went back to sleep, perhaps for another 300 years. Where forest had been, only a few broken tree stumps now stood above the valley's dusty floor. Remains of the forest and its litter of leaves, cones, and needles lay buried beneath a blanket of ash and volcanic debris.

Mineral-bearing waters below the surface had already begun to petrify the buried tree trunks. During the rainy seasons some of the tributary valleys had spewed out long tongues of volcanic mud-flows, heavily laden with volcanic fragments and boulders, onto the valley floor. The landscape stood barren of signs of life, either animal or vegetable.

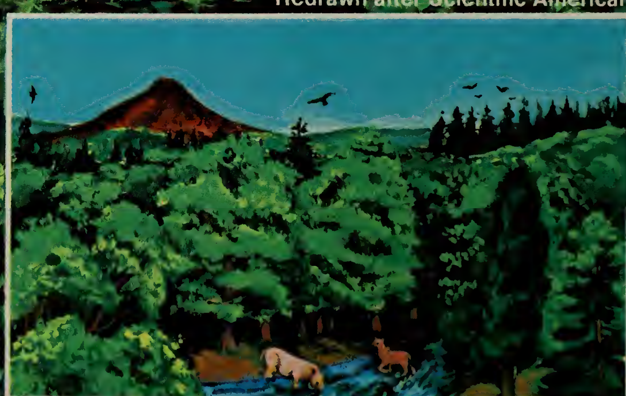
Within roughly 200 years a new, green forest finally began to reclothe the valley. The air was clear, the sky blue, and the sun shone. Little by little the larger animals and birds and insects returned. Quiet prevailed again. In another 300 years, while the old volcano slumbered on, the forest grew again to its former luxuriance and splendor. Buried beneath its roots were the petrified trunks and fossilized leaves of the previous forest.

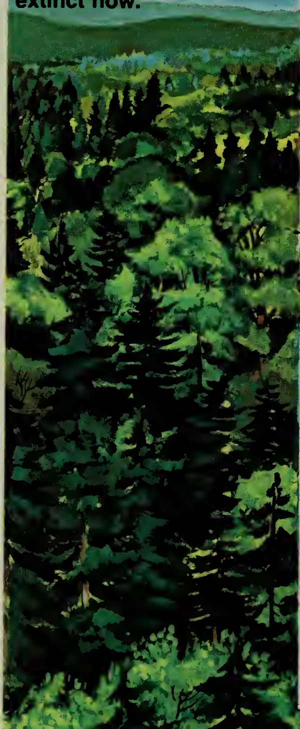
Would the old volcano awaken again and start the whole devastating sequence anew? The chances seemed against it, but sure enough it happened—not once or twice, but more than 25 times!

Volcanic Episodes 50 Million Years Ago

Periods of volcanism alternated with calm periods for some 20,000 years. Between eruptions the Eocene Epoch forests recovered–until the next eruptions decimated and buried them (facing page). Three insets on this page show (top to bottom) earthquakes shaking the trees before an eruption; the eruption and the destruction of the forests; the Eocene Epoch forests recovered in a period of calm. The broadleaf forest cover is not typical of today's Yellowstone. The rhinoceros and eohippus shown are of course extinct now.

Redrawn after Scientific American






Successive eruptions buried 27 separate forest layers

The Most Remarkable of Their Kind

The height of individual stumps (below) varies from 1 to 4.5 meters (3 to 15 feet). The eroded ridge (right) exposes several of the 27 forest layers buried one on top of the other. Fossil stumps stand here among living trees.

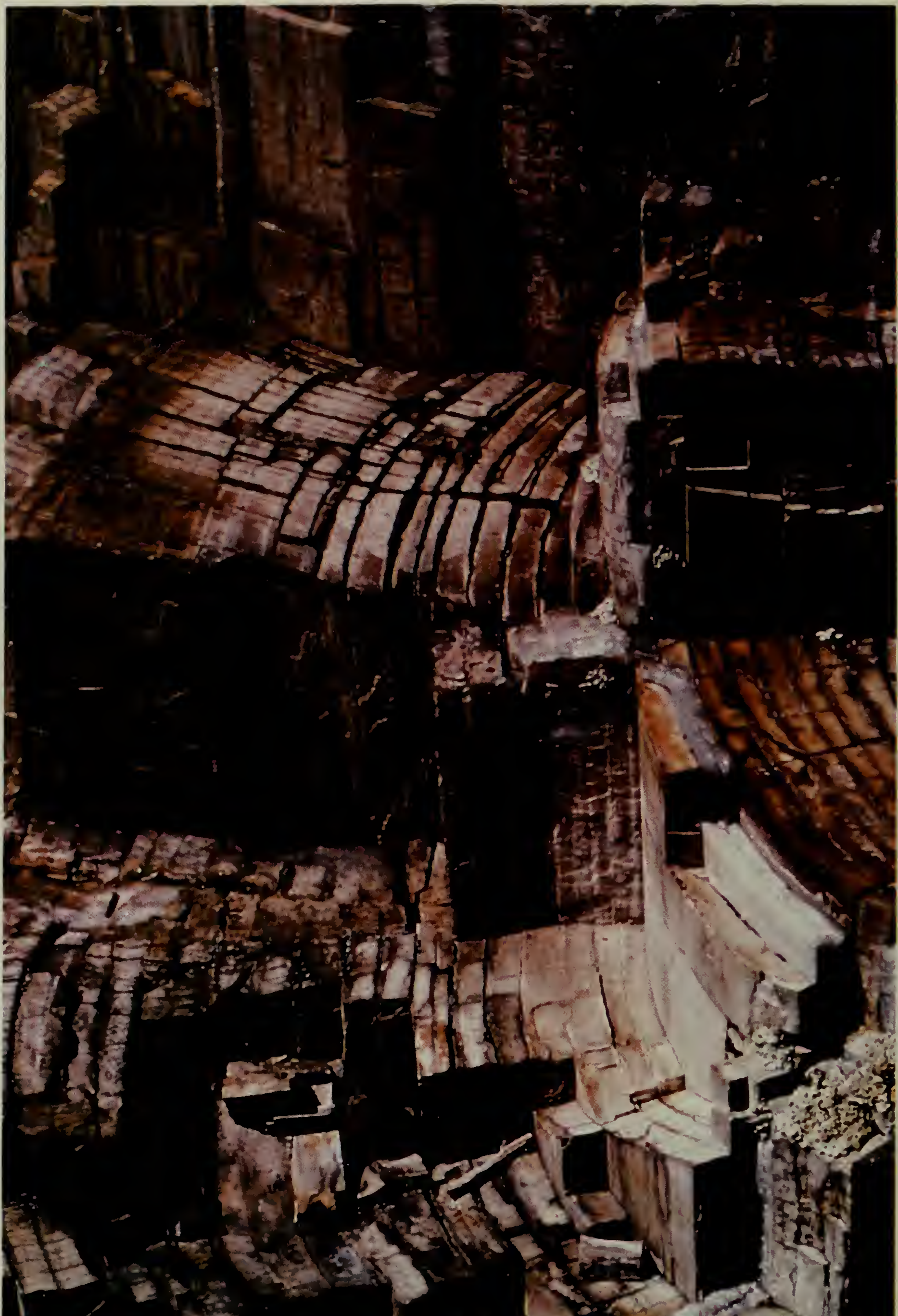
The fossil forests of Yellowstone are in many respects the most remarkable in the world. Their size is unparalleled. Their more than 64 square kilometers (24.5 square miles) cover a larger area than any other fossil forests known. They are the "deepest" too. Twenty-seven separate forests were buried, one at a time, right on top of one another.

Yellowstone's petrified forests are also distinctive because they look like decapitated forests. The hundreds of petrified stumps mostly still stand upright where they grew millions of years ago. Here and there erosion has exposed not only the upright petrified stumps, but also their spreading roots and rootlets. In many places trunks and branches lie prostrate, just as they fell from the upright trees during the violent volcanic outbursts.

After each forest had grown to maturity and was buried by volcanic debris, a period of calm passed. The forces of violent change took a breather. This peaceful period was long enough to allow soil to develop and a new forest to grow on top of the debris and buried remnants of the old. The new forest was then buried by the next volcanic outburst. This alternation of volcanic activity and quiet periods of forest growth took place over thousands of years, eventually accumulating approximately 366 meters (1200 feet) of volcanic materials.

The volcanic rocks in Yellowstone's fossil forests have also produced thousands of beautiful fossilized leaves, twigs, needles, cones, and seeds from more than 80 kinds of trees and shrubs. The best and most faithfully preserved are buried in fine volcanic ash.

The volcanic eruptions that buried Yellowstone's fossil forests represent our earth bent on changing in a hurry. It is not always in such a rush. Slow change has revealed the petrified forests to our view: Raindrops and running water joined forces with time to sculpt the earth, relentlessly carving back its often secretive mantle. This slow process of erosion exposed these many forests that were petrified almost 50 million years ago.



How Fossils Happen

Fossils are the remains or traces of animals or plants which have been preserved by natural causes in the earth's crust. To petrify means "to make into rock." Petrifaction, a form of fossilization, is responsible for the transformation of buried stumps or logs into petrified wood. Shells and bones, too, can be petrified.

The process is not yet completely understood, but it is no longer believed to be what old textbooks described as the "molecule-by-molecule replacement of the plant materials by mineral matter." In most cases the mineral matter does not replace the plant materials. It merely fills in the cavities within and around empty cells of the wood. The wood's tough cellular walls are surrounded and embedded in more or less their original state. Growth rings and delicate microscopic details of cellular structure are usually beautifully preserved.

Petrified wood in the Yellowstone region is almost always silica, (i.e. quartz). The silica comes from the volcanic debris itself, circulated through the buried trees by surface and subsurface waters. Some of these waters were probably quite hot. On a highly polished surface of the petrified wood the silica can be dissolved away by immersing it in hydrofluoric acid. A projecting residue of the embedded wood is left behind, with its cellular structure almost perfectly preserved. It usually retains its original shape and woody consistency well enough to be sectioned into thin slices. It can be studied just as modern wood is studied.

Fossilization occurs only when conditions are just right. Most dying plants and animals are decomposed. They are broken down into more basic elements and returned to the earth's storehouse of raw materials for coming generations. We call this decay, and often think of it as a negative process, but decay recycles nutrients to build future life. Fossilization sometimes intervenes, however.

The rapid burial of leaves, needles, or entire forests in fine volcanic ash or dust creates good conditions for fossilization. It prevents decay, and plant remains are preserved as either compressions or

Scientists study petrified wood specimens (left page) just as they do modern wood, by sectioning them in thin slices (below).

Petrified Forests Reveal Eocene Climate

The fossil trees' nearest living relatives now grow in warm-temperate to subtropical forests. Today, Yellowstone's forests typify cool-temperate to subarctic climate.

The silica forming most petrified wood here (below left) comes from the volcanic debris. Water circulated it through the trees. Impurities—oxides of iron or manganese—can color the silica.

Leaves are fossilized as compressions when immense weight presses organic material out. Leaf impressions form in soft mud or sand, showing negative or concave features.

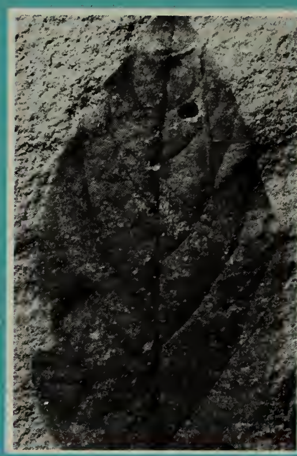
Oxide Impurities Create Color

Iron Oxides Coloration

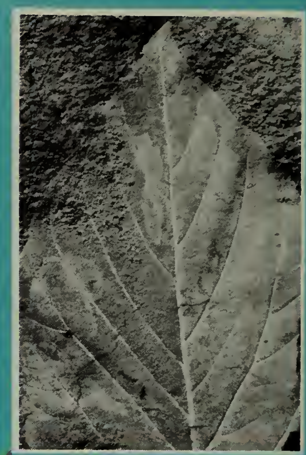
Manganese Oxide Coloration

Pure Silica

A Fossil Leaf Compression



A Fossil Leaf Impression



Sycamore Leaf
50 Million Years Ago

Sycamore Leaf
Today

A Tree Evolves

Contemporary and ancient sycamore leaves show differing numbers of lobes (right). The ancient leaf is shown with an actual fossil photograph inset.

Climate Change Changes Trees

Sycamores (left), broadleaf hardwoods, were typical of forests fossilized in Eocene times. Coniferous lodgepole pines (right) are typical today.

impressions. In rare cases the remains of buried fruits, seeds, cones, and even flowers may be preserved this way.

Compressions are formed when most of the organic material is pressed out of plant parts by the immense weight of rock layers above them. Only the thin and extremely tough cuticle or skin of the plant is preserved. When the enclosing layers of rock are carefully removed, the compression looks like a thin layer of carbon pressed against the rock. Compressions often show great detail and can be valuable in helping researchers reconstruct what prehistoric plants looked like and how they may have developed.

Impressions are formed when plants come into contact with a soft surface of mud or sand. They usually occur as negative or concave features, like a mold of the original. These imprints preserve the external structural features of the plant parts. By running your thumb and forefinger over the surfaces of many leaves you can feel which features might be preserved as fossil impressions.

Although they are rarely found in volcanic deposits, the remains of microscopic pollen grains and spores were recently recovered in the Yellowstone region. They were chiefly collected from the cliffs above the Lamar River. Remains of a few fossilized bones and teeth have been collected from the volcanic rocks east and south of Yellowstone Park, but no animal remains have ever been found in the volcanics within the park. Living animals and birds are believed to migrate out of an area as soon as the ash and dust in the atmosphere make breathing difficult.

Lessons Locked in Stone

Fossil plants are stones that speak. They tell us of a past unimaginably beyond human memory. They tell us what the landscape, or topography, was like here when the volcanoes erupted. They recall for us the flora, or plant communities, characterizing that era. They speak of climate and how it differed from today. Finally, they can help us gauge how fast volcanic materials were belched out and deposited on the earth's surface.

Yellowstone's fossil plant-bearing beds are largely

horizontal and very wide. This evidence tells us that the original forests grew in relatively large flat valleys. The repeated burial and destruction of the many successive forests gradually raised the valley floors but did not alter the general flatness of the terrain between the higher volcanic hills and cones.

Careful study of the fossil plants in Yellowstone's volcanic rocks has revealed forests composed of more than 80 plant species. The petrified wood and fossil leaves, needles, cones, and seeds include some 8 species of ferns, 2 horsetail rushes, 7 conifers, and 68 flowering plants.

The successive buried forests show minor differences. However, the most common species, measured by their relative abundance as fossils throughout the many layers, were sycamores, walnuts, magnolias, chestnuts, oaks, redwoods, maples, persimmons, and dogwoods. The nearest living relatives of these tree species are native to today's warm-temperate to subtropical forests.

Other common species represented in these fossil forests include laurels and bays. Today's nearest living relatives of these trees are more at home in the tropics than in the cool-temperate forests of today's Yellowstone Park. Exotics, trees not native to this region, were represented here by ancient relatives of the living oriental katsura tree (*Cercidiphyllum*) and the east Asian chinquapin (*Castanopsis*). Their descendants had disappeared from the North American continent before the Tertiary Period ended. Other important members of the buried Yellowstone forests were climbing ferns, pines, soap-berries, hickories, bay-berries, elms and willows.

Additional plants will probably be identified in the collections of pollen and spores recently made from Yellowstone's volcanic deposits by Lanny H. Fisk. Already identified at Harvard University in petrified wood specimens are alder, ironwood, magnolia, elm, sycamore, oak, and myrtle. These specimens will likely result in further identifications.

Fossils speak of climate only indirectly. We must compare how fossils relate to their modern forms to draw conclusions because climates themselves are not preserved. Scientists begin by assuming the ancient forests had the same climatic requirements as their counterparts of today. These comparative studies indicate that climatic conditions in Yellowstone

during the Eocene Epoch approximated those in today's southeastern and south-central United States.

The conditions probably ranged from warm-temperate in the rolling uplands to subtropical in the flat lowlands. Rainfall probably averaged between 130 and 150 centimeters (50 and 60 inches) per year. The entire region was then characterized by broad, flat, lowland valleys bordered by relatively low, rolling mountains probably nowhere more than 914 meters (3,000 feet) above sea-level. By contrast, elevations in Yellowstone Park today average about 2,133 meters (7,000 feet) rising to more than 3,658 meters (12,000 feet) in the Absaroka and Beartooth ranges east and northeast of the park.

The forests of today's Yellowstone contrast strikingly with the vegetation represented in its fossil forests. Present forests are dominated by evergreen conifers with a minority of deciduous, hardwood species. The reverse was true in the buried fossil forests, where hardwoods were dominant.

The coniferous forest of today's Yellowstone region is essentially a southward extension of the lowland northern coniferous forest of central Canada. Chiefly a spruce-fir forest, it also contains pines and a few hardwoods. Yellowstone's highest peaks and ridges reach above the treeline and are therefore occupied by virtually treeless alpine meadows. Below these occurs the zone in which the stately Engelmann spruce and the alpine fir are the dominant trees. Still lower, and representing the greater part of the Yellowstone Plateau, is the coniferous belt in which the lodgepole pine prevails, mixed with minor stands of spruce and Douglas-fir.

Along the mountain slopes the conifer forests are often broken up by scattered groves of quaking aspen whose golden coloration lends spectacular beauty to early autumn in Yellowstone. Other deciduous hardwoods include the common lowland cottonwood and scattered birch. Several species of willow and alder grow along the stream valleys. Common shrubs are the gooseberries, currants, and wild roses.

Yellowstone's contemporary forests typify a cool-temperate to subarctic climate, in contrast to the warm-temperate to subtropical climate indicated by its fossil plants. Further evidence from western North America suggests that the climate continued to get warmer in late Eocene-early Oligocene time.

Then the warming trend reversed. This cooling trend, especially noticeable in the northern hemisphere, continued throughout the world with occasional warmer episodes. As the Pliocene Epoch ended, ice caps had begun to form in Canada and northern Eurasia, ushering in the Ice Age.

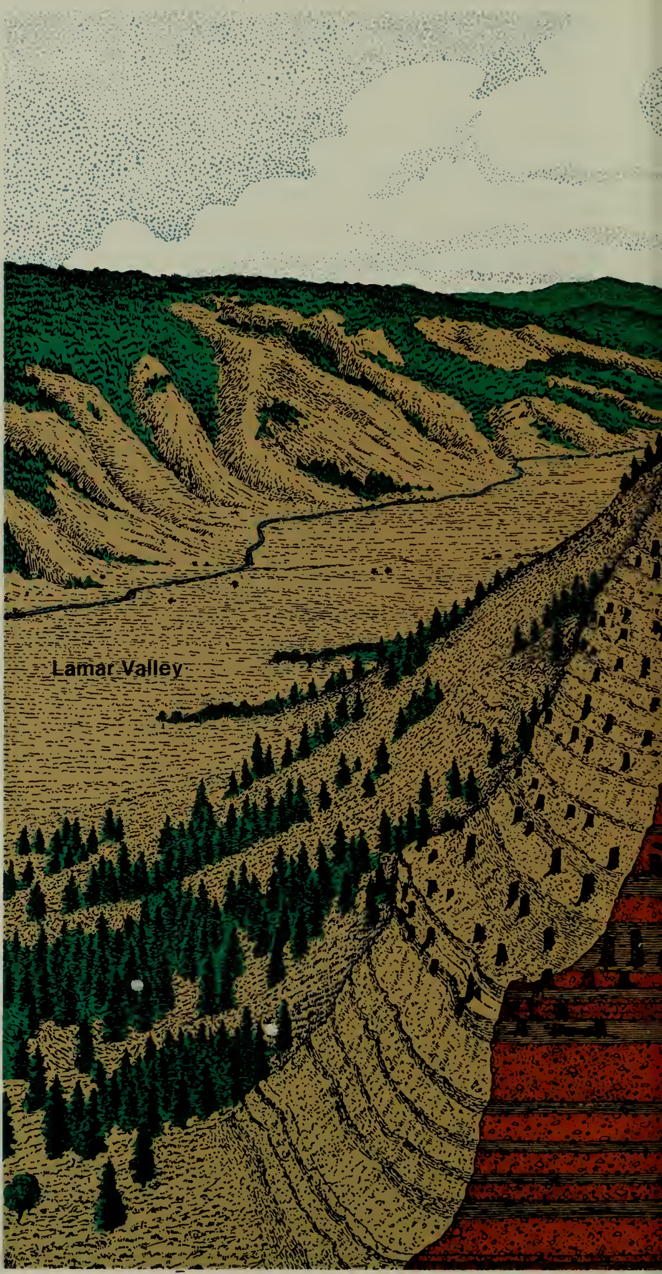
Studies in present-day volcanic regions show that volcanic debris and ash deposits are usually laid down at much more rapid rates than other geologic deposits. Yellowstone Park provides an unusual opportunity to estimate the actual rate of these deposits in the vicinity of one of its fossil forests. Most petrified stumps here average about 500 annual growth rings. It is also evident that each petrified forest was buried by a single deposit of volcanic materials, in most cases to a depth of 3 to 4 meters (10 to 15 feet).

Studies of an active volcanic region in Mexico show that new forests can begin to grow about 200 years after a region has been buried by volcanics. Using these data as averages for the 27 forests exposed in Yellowstone, it can be calculated that approximately 20,000 years were required to deposit the 366 meters (1,200 feet) of volcanic sediments which cover the forests. This represents about 1.8 centimeters (0.72 inches) per year, an extremely rapid rate. By contrast, shallow-water marine sediments of the same age in the Gulf Coast region are calculated to have been deposited at a rate of only .018 centimeters (0.007 inches) per year. The rate of deposition for Yellowstone volcanics was therefore roughly 100 times that of the Gulf Coast sediments.

A fossil stump still standing where the tree grew millions of years ago can be seen from your car near Tower Junction. It was fenced early this century because many others here were taken—piece by piece—as souvenirs, an irreplaceable loss. All fossils in the park are now protected by law.

The Petrified Formations in Geologic Time

The 27 fossil forests buried in Specimen Ridge originally grew in a broad, flat valley. The geologic time scale at right shows the relative position of the Eocene Epoch in the broad sweep of earth time. The repeated volcanic eruptions that buried the forests took place over about 20,000 years. This all happened 50 million years ago. Geologists generally place earth's beginnings at 4.5 billion years ago.



Geologic Timetable
(in millions of years)

Cenozoic Era
- Quaternary Period
  - 0.01 Holocene Epoch
  - 3 Pleistocene Epoch
- Tertiary Period
  - 13 Pliocene Epoch
  - 25 Miocene Epoch
  - 38 Oligocene Epoch
  - 54 Eocene Epoch
  - 65 Paleocene Epoch

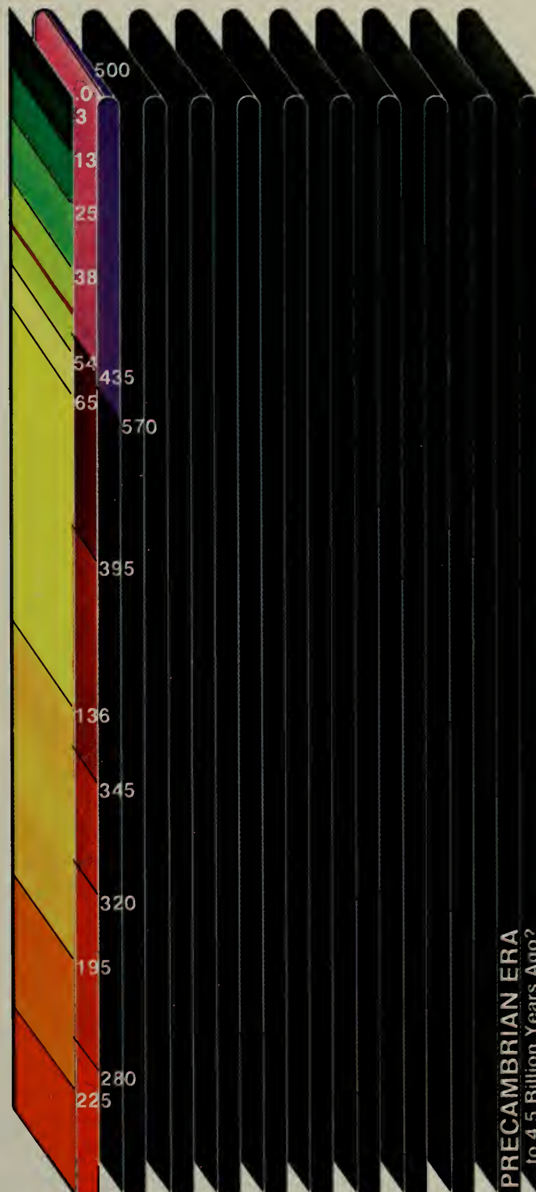
Mesozoic Era
- 136 Cretaceous Period
- 195 Jurassic Period
- 225 Triassic Period

Paleozoic Era
- 280 Permian Period
- 320 Pennsylvanian Period
- 345 Mississippian Period
- 395 Devonian Period
- 435 Silurian Period
- 500 Ordovician Period
- 570 Cambrian Period

Precambrian Era
to 4.5 Billion Years Ago?

Credit: Scientific American

Geologic Timetable (in millions of years)



The Forests' Age, and Geology

The volcanic activity that buried entire forests in Yellowstone National Park took place millions of years ago. The precise date and duration of this episode may never be known, but the position the area's volcanic rocks occupy in geologic time can be determined.

Geologic time is divided into four units, called "eras." The first and oldest era was the "Precambrian," followed in turn by the Paleozoic, the Mesozoic, and the latest era, the Cenozoic. Each era lasted millions of years and is subdivided into "periods" which themselves lasted many million years.

The Lamar River flows over Yellowstone's oldest rocks–some 2.7 billion years old. The ridge above contains 27 layers of fossil forests that originally grew in a broad river valley.

Volcanic rocks occur in Yellowstone on top of rocks whose fossils belong to the latest epoch of the Cretaceous Period. The volcanics must therefore be younger than Cretaceous, belonging to either the Tertiary or the Quaternary Period. Comparing the fossil plants of Yellowstone's volcanic rocks with species known elsewhere in North America more accurately places the fossil forests in the Eocene Epoch in the early Tertiary Period.

Detailed comparisons reveal that the Yellowstone fossil plant assemblages range in age from the latest part of the Early Eocene to the early part of the Middle Eocene Epoch. Other fossil plant assemblages of approximately this same age have been collected in the Rocky Mountain Region. They are found in the Green River oil shales of southwestern Wyoming and northwestern Colorado, the Kisinger Lakes-Tipperary flora of west-central Wyoming, the Aycross beds of west-central Wyoming, and volcanics southwest of Cody, Wyoming.

The actual number of years involved in most of the divisions on the geologic time table can now be determined by sophisticated methods that measure the decay of radioactive materials. These methods have been applied to the mineral sanidine from a petrified forest area in Yellowstone Park. The results give an age of 49.2 million years, plus or minus 1.5 million years. This essentially agrees with the evidence previously provided by the fossil plants, which placed the Yellowstone volcanics episode in the late Early Eocene to early Middle Eocene.

Geologists estimate that the Eocene Epoch began approximately 58 million years ago and ended about 36 million years ago. This is the time-frame of the fossil forests. As geologic time is measured, the Eocene is a fairly recent epoch in the earth's history. It falls within the Cenozoic Era, the era of modern life, characterized by plants and animals comparable to those still living today.

To study an area geologists classify it in related geologic units. The largest distinguishing unit is called a supergroup. It can be subdivided into groups, which are subdivided into formations. Formations may or may not contain several members.

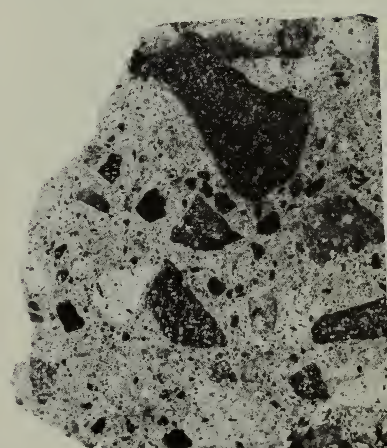
We identify the petrified forests of Yellowstone, based on such classifications, as follows: they occur in the Absaroka *Supergroup* of the Yellowstone Park Plateau as a part of its Washburn *Group.*

Most rocks in Yellowstone National Park are of volcanic origin. They include solidified volcanic lavas, cemented volcanic fragments, pebbles, ash, and even dust. In the greater Yellowstone region the estimated composite thickness of these volcanic deposits is more than 3 kilometers (1.9 miles). Within the park they reach a maximum thickness of about 1,520 meters (5,000 feet). This volcanic material extends eastward from the Yellowstone Park Plateau into the Absaroka Mountains almost to Cody, Wyoming. Northward it reaches almost to Livingston, Montana, and southward to the northern flanks of the Teton Mountains. To the west the plateau joins the eastward extension of the well-known Columbia Plateau, North America's largest volcanic plateau.

Yellowstone's petrified forests occur within two thick units of debris and lavas in the lower half of the volcanic material's total thickness within the park. These units consist mainly of volcanic breccias, angular fragments embedded in solidified ash; volcanic conglomerates, rounded pebbles embedded in solidified volcanic sediments; and tuffs, solidified volcanic ash or dust. These are sometimes interrupted by layers of basalt, dark, fine-grained, solidified basic lava; and welded tuffs, hot volcanic ash solidified by heat-welding of grains. The petrified forests are exposed in these two geologic units, the Sepulcher and Lamar River Formations.

The Sepulcher Formation—The thickest (579 meters/1,900 feet) and best exposed section of the plant-

Volcanic breccia (shown below) is formed of coarse debris cemented together by mud. The finer-grained tuffs represent deposits of ash and dust.



Looking down on the Lamar River valley from atop the upper layers of exposed fossil forests accentuates the thickness of the 27 layers buried between this ridgetop and the valley floor below it.

bearing beds runs from the top of Crescent Hill northward to the Yellowstone River. Its predominantly light-colored, fine volcanic sediments include both volcanic sandstones and tuffs formed by ash falling out of the air. These are both composed of andesite, with shiny flakes of biotite mica. The minerals hornblende and pyroxene, appearing as darker grains in the light-colored rocks, are also common. This formation is interbedded with thin units of volcanic breccias and conglomerates and thicker units of basalt and welded ash-flow tuffs. The Elk Creek Basalt Member of the Sepulcher Formation reaches thicknesses up to 90 meters (300 feet) and the Lost Creek Tuff Member up to approximately 105 meters (350 feet). Both of these members become thinner and pinch out eastward, where they interfinger with the lower portion of the Lamar River Formation. Plant remains of leaves, needles, and seeds occur abundantly in the finer volcanic sandstones as well as in the air-fall tuffs.

The conglomerate at the base of the Sepulcher Formation measures up to 30 meters (100 feet) thick. It is best exposed in the lowermost cliffs along the Yellowstone River upstream from the mouth of Hellroaring Creek. It is composed mainly of large pebbles and boulders of granitic rocks up to 2.5 meters (8 feet) in diameter.

Lamar River Formation—The best and thickest (305 to 610 meters/1,000 to 2,000 feet) sections of this formation are found in the bold cliffs along Specimen Ridge and below Amethyst Mountain. This is mostly composed of clearly bedded, coarse to fine, medium brown volcanic conglomerates and breccias, interbedded with finer volcanic sandstones, siltstones, and tuffs composed of andesite, without biotite. A few thin basalt lava flows occur in the upper part and a thick basalt (the Elk Creek Basalt Member) in the lower part. Abundant plant remains are found throughout this formation. They include many standing petrified trunks as well as zones of leaves, seeds, needles, and cones.

The fossil forests of Yellowstone National Park were buried in volcanic debris of several types. This debris is believed to have originated in volcanic cones in or near the present park. The main body of the Sepulcher Formation came from the horst area of the present Gallatin Range, to the west. The La-

Where were the Volcanoes?

Yellowstone's Landscape Today

Yellowstone's Landscape 50 Million Years Ago

mar River Formation originated chiefly from the Washburn Volcano, only 19 to 21 kilometers (12 to 13 miles) to the southwest. The present Mt. Washburn is an eroded remnant of this volcano. Additional debris here probably came from volcanoes to the northeast and east of what is now the park.

The volcanic conglomerates and volcanic sandstones are distinctly layered when seen as a cross section. These were probably laid down as stream deposits. The volcanic breccias are not layered, so geologists think they were formed by extensive mud flows. Petrified trees occur in all these deposits. Apparently, this coarse debris buried the forests so gradually that few trees were knocked over or even tilted from their upright position.

The finer-grained tuffs contain numerous remains of fossilized leaves of hardwood trees and conifer needles and cones. They represent the fine volcanic ash and dust deposited partly in sluggish streams and lakes and partly as air-borne debris that settled down directly on the land surface. Petrified trees are less common in these tuff beds than in the coarser debris, but these beds help to complete the story of what happened here millions of years ago.

Petrified Forest National Park, Arizona (top), contains this country's most famous fossilized trees. Most were not preserved upright where they grew. They lie where an ancient river left them stranded. Other petrified trees occur in California and Oregon, and in England, Egypt, and Australia. Related fossil forests are found just outside Yellowstone Park in Gallatin National Forest (photo above).

Could It Happen Again?

The concentration of so many hot springs and geysers in Yellowstone Park shows that great subterranean heat lies barely below the surface. One wonders whether the park's landscape might again become smothered in extensive lavas and ash beds. And if so when?

World-wide observations reveal that temperatures below hot springs and geyser basins are abnormally high. Drilling in such areas has demonstrated that subsurface temperatures range from 150° C (300° F) to 204° C (400° F). The U.S. Geological Survey's deepest hole in Yellowstone, drilled at Norris Geyser Basin, recorded an even higher temperature of 240° C (465° F) at a depth of 332 meters (1,088 feet). Further measurements indicate that the total heat flowing from the Upper Geyser Basin is now at least 800 times greater than normal. These observations have led to the belief that a large chamber filled with hot molten rock, produced by what is

called a magma plume or mantle hot-spot, lies below the surface in Yellowstone at a relatively shallow depth. (See diagram, pages 4–5)

Is there any further evidence to indicate that this subsurface magma is getting ready to move closer to the land surface and produce volcanic eruptions? The last explosive volcanic eruptions which smothered the entire Yellowstone region with thick beds of hot pumice, cinders, rock particles and ash occurred about 600,000 years ago during the Ice Age, in the Pleistocene Epoch. These are the ash-flow tuffs or welded tuffs geologists describe as the Yellowstone Tuff Formation. There are no known occurrences of petrified trees or logs nor of leaf remains in these deposits, presumably because all the vegetation living at that time was completely burned by the intense heat which accompanied the ash-flow tuffs.

Even more pertinent is the evidence that volcanic activity in the Snake River Plain of Idaho has been slowly shifting toward Yellowstone Park from the southwest during the last 15,000,000 years. This movement is believed to have been the subterranean trace of a mantle hot spot which has now moved directly under Yellowstone Park. It seems reasonable to conclude that the underground prelude to further volcanic activity in the Yellowstone region has already begun. Whether the final act will involve quiet surface lava flows or explosive eruptions of pumice and ash, or both, remains to be seen. Further conjecture about exactly when such volcanic events might occur in the Yellowstone region would be just that, conjecture.

Though scientists are cautious and reluctant to speculate on such issues, the evidence would seem to point to a recurrence. Just what kind of volcanic or other activity would occur; how far it would reach; and what damage it might do are for the future to reveal. But Yellowstone National Park's numerous visible geothermal features make it apparent that this planet is a powerfully active force characterized by periodic, often violent, change. Here as elsewhere, it could happen again!

A 1959 earthquake dramatized Yellowstone's geologically active nature. This paved road near the park broke up in large chunks. The earthquake caused an immense landslide that dammed up the Madison River to create a new lake, Quake Lake.

National Park Service

Resources Protected by Law Petrified trees in Yellowstone National Park are protected by law because of their rarity, scientific value, and the fact that they are in a national park. Specimens must not be broken or taken from the park. The National Park Service, responsible for management and protection of these petrified trees, requests your cooperation in the continued enjoyment of these and other natural treasures of Yellowstone National Park.

For Further Reading

The Geologic Story of Yellowstone National Park by William R. Keefer, U.S. Geological Survey.
Stratigraphic Framework of the Absaroka Volcanic Supergroup in the Yellowstone National Park Region by Harry W. Smedes and Harold J. Prostka, U.S. Geological Survey Professional Paper No. 729–C.
Yellowstone Park as a Window on the Earth's Interior by Robert S. Smith and Robert L. Christiansen. Scientific American, February 1980.
Depositional Environment of the Yellowstone Fossil Forests as Related to Eocene Plant Diversity by W. J. Fritz. Geological Survey of America Abstracts 11(7):428, 1979.

Illustrations

Salvador Bru front cover.
Jerry Miller 12-13; 18-19; 29.
James True and Don Christian 4-5; 25.
Scientific American 24.
All photos are from the collections of Erling Dorf, Yellowstone National Park, and the National Park Service.

☆GPO: 1980—311-340/5

U.S. Departm
of the Interior

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

Petrified Forests of Yellowstone